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OBSERVATIONS ON A FATIGUE PHENOMENON

by

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SUMMARY

In this work, the experimental results of an investigation on a fatigue "phenomenon" are reported. It has been found that the endurance limit may be found nondestructively and that the specimen under examination exhibited the existance of an extremal value in the neighborhood of the endurance limit even though the machine employed, a GE pneumatic fatigue machine, has no moving parts.

Furthermore, it has been observed that the frequency has an apparent influence on the sensitivity of the "phenomenon."

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Definition of Terms

"Fatigue Phenomenon": It has been observed that when a specimen has been subjected to a relatively small number of cycles in a preassigned stress field which is progressively increased from test to test, the "damping" characteristics of the specimen exhibits an extremal value in the neighborhood of the "endurance limit". This indication of change of the "damping" is referred to in this report as the "fatigue phenomenon" or merely the "phenomenon".

"Endurance Limit": Is understood to be the asymptotic value the stress approaches as the number of cycles increases indefinitely, in the stress vs. cycles conventional fatigue curve.

Acknowledgement

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A Summary and Some Recommendations

With the allocation of funds for technician time by the idea processing fund of the Mechanical Engineering Laboratory, some overhead technician time donated by the Applied Mechanics Section, and materials and machine fatigue specimen supplied by the Research Laboratory, a research program was undertaken whose primary purpose was to investigate the following areas:

(1) The effects, if any, of the type fatigue machine on the previously observed "fatigue phenomenon".

(2) The influence, if any, of the frequency of excitation on the "fatigue phenomenon".

To achieve the above goals a series of tests were run using a G.E. pneumatic fatigue machine activated by compressed air or by a magnetic field. The specimen available for this phase of the project were made of 347 stainless steel, 1020 steel, 6061 aluminum, polystyerene and plexiglass.

This set of experiments disclosed the following observations:

(1) The relationship between damping and stress shows the exsistance of an extremal value at the "endurance" limit.

(2) The type of fatigue machine used seems to have some influence on the nature of the damping stress relationship.

(3) The extremal value, however, still occurs at the endurance limit in all tested cases.

(4) The driving frequency has some effect on the damping vs. stress relationship. This small series of experiments was not sufficient to establish clearly the nature of the influence of the driving frequency.

(5) When the driving frequency coincides with the natural frequency of the specimen, the curves exhibit singular extremal points at the endurance limit.

This series of tests demonstrated, to a fair degree, the possibility that the fatigue behavior of specimen, machine parts, etc. can be predicted by non-destructive methods, at least for the class of structural materials. Furthermore, the conception and development of an apparatus designed to take advantage of this new observation is considered to be a distinct possibility since it was demonstrated the fatigue "phenomenon" under consideration was sharply excited under some conditions.

Under the available experimental set up and funds to this project it was not possible to investigate to a satisfactory degree the behavior of plastic materials. Better control equipment were necessary and more time for instrumentation.

In view of the results of this short study it is recommended that a serious and systematic investigation be undertaken whose goal be the understanding of this "unconventional" behavior of materials and the design of a machine or apparatus to take advantage of it. A start in this direction could be the following program:

1. A theoretical investigation aiming in unvailing the basic reasons for the existance of this phenomenon.
2. An experimental investigation whose objective shall be:
   a. The effect of variation of the frequency of excitation on the phenomenon, for frequencies above the first critical.
   b. Continue the investigation on other materials not yet tested, such as, plastics and exotic metals.

This phase will require improvement of the existing experimental set-up.

   c. The effect and influence of temperature and of environmental conditions on the phenomenon.

These experiments may furthermore indicate the range of existance of this "phenomenon".

The Program

Under the facilities provided for this program an experimental program was devised with primary purpose to show whether or not the "fatigue phenomenon" previously observed was solely the effect of the massive conventional fatigue machines used or it really represented some physical properties of the materials thus far tested. To attain this goal, it was necessary to use apparatus and instruments whose moving parts were kept to a minimum. Also the specimen had to be of the simplest possible geometric form in order to remain within budget.

Limited by these requirements a GE pneumatic fatigue machine was reconditioned and instrumented. This type of machine activates the specimen by means of two jets of pressurized air which impinge on two recepticals attached to the specimen. This machine is equipped with variable pressure and a series of trombones capable of varying the driving frequency. It is thus possible to excite a specimen in the neighborhood of its natural frequency over a reasonable range of stress levels. The stress range is limited by the clearance between the jet nozzles and the recepticles attached to the specimen. The specimen was mounted as a cantilever beam in this series of experiments. As printed above, the pneumatic machine can drive a specimen over reasonable range of stress only in the neighborhood of the natural frequency of the specimen. To achieve a variable driving frequency without resorting to a number of specimen with different geometric parameters a magnetic field was employed replacing the compressed air jets. The magnetic field was used in the investigation of the effect of the variation of driving frequency on the fatigue "phenomenon".

Since the end conditions affect the stress field and there exists some degree of variation on the manner by which the specimen is fixed to the testing machine, each time a specimen is tested, it was attempted to find the

effect on the investigation by employing two types of end conditions. In the first, the specimen was bolted down directly in to the fixture, in the second, a rubber padding was introduced between the specimen and the fixture.

The essential measurements and observations in this series of tests consisted of:

(I) The maximum stress.
(II) The maximum deflection.
(III) The number of preload cycles.
(IV) The coast down cycles.
(V) The driving frequency.
(VI) The end conditions.

The maximum deflection was measured optically and checked by strain gage measurements attached to the specimen. The coast down cycles were counted by means of a capacity pick up and checked by the strain gage traces. Most of the above functions and observations were done automatically by means of electronic equipment.

The experimental set up, whose basic requirements were described in the above paragraphs, was instrumented by Mr. F. Madden, an engineering technician at MEL. A schematic representation of the instrumentation is given in Figure 2. A short description of the instruments and equipment use along with some comments by Mr. Madden can be found in the appendix at the end of this report.

The Experimental Results

The results of this program are given in terms of groups of graphs. These graphs represent the functional relationship between the maximum stress and the coast down "damping" for a variety of conditions. It is not intended to give in this report all the data obtained during the course of this investigation. Instead, only a representative group is chosen which, however, engulfs all the essential and meaningful information obtained in this program. Also, the tests on the plastic materials, are not included in this work, since it was found that they tend to vibrate over undesirable patterns with amplitudes difficult to control with the available equipment; thus leading to meaning-less results.

Comparing the functional relationship between figures 3 through 11 which are the graphical representation of the results of tests on the pneumatic or magnetically driven machines and that of figures 12, resulting from tests with the Sontag machine, it is apparent that the form of the curves is not the same. The group of graphs that employed the non-moving parts machine shows a gradual increase in coast down count up to a smooth maximum then a gradual decrease. In contradistinction, the massive Sontag machine tests indicate virtually no change of count down with increasing maximum stress at low stresses, and a rather clear smooth change around the neighborhood of the endurance limit.

Considering the tests performed with the pneumatic machine it is apparent that the maximum occurs in the immediate neighborhood of the so called "endurance" limit. It seems, therefore, that although the relationship between maximum stress and "damping" is not identical in both cases, the coincidence of the endurance limit with the extremal of the curve remains unchanged.

Each bar in this series was tested eight times. Only three runs are reported here in order to avoid unnecessary conjestion of the graphs. The figures 3 through 8 indicate that maximum or minimum appears at the same stress for various runs. This implies good repeatibility and also that this type of test is virtually a non-destructive one.

This short series of tests were not sufficient to establish a clear picture of the effect of the driving frequency on the "phenomenon". There seems to be some influence on the coast down vs. stress curve as may be seen from figures 3 through 8. A more complete coverage of the range of frequencies would possibly yield enough information to fill this gap. The need for a more thorough investigation is exemplified by the test results at the natural frequency of the specimen, as shown in figure 11. This figure indicates a radical chance in the functional relationship between "damping" and stress level. Its extremal values are singular points approached sharply, almost asymptotically. The extremal values correspond to the "endurance" limit, however. Thus, it seems that an orderly transition from the smooth curves to this singular asymptotic casps must exist. Figure 11 points out another interesting observation: The "endurance" limit is very accurately and clearly found, since it corresponds to the singular extremal values. However, the amplitude control at the natural frequency is rather difficult, thus, in an adverse manner compensating for the very accurately defined "endurance" limit.

Figure 9, which represents the tests done with rubber padded fixed ends, shows that the "damping" vs. stress curve is somewhat damped down, but still clearly showing a maximum. Furthermore, there is an apparent shift of the maximum, but is expected since a change in end conditions implies a change in the stress field.

It should be noted here that all the tests were not as successful or easily interpreted as the ones mentioned thus far. There were some whose results would have been difficult to understand with the aid and guidance of the successful one. Such an example is given in figure 10.

In summary, one may say that this series of tests have shown that,

- I. The existance of the fatigue "phenomenon" is not solely a function of the machine employed, since it clearly appears with a fatigue machine with no moving parts.
- II. There is an influence of the driving frequency on the form of the response curve, but its nature was not found in this short series of tests.
- III. The curves at the natural frequency of the specimen have a sharply defined "endurance limit".
- IV. Changes at the end conditions are detected by this type of non-destructive testing.

It may be of interest to note the range of values of the endurance limit of the materials tested here as reported in recognized references such as the "Metals Handbook":

1020 Steel Hot Rolled	26000	to	33,000 psi
Cold Rolled	31000	to	39,000 psi
347 Stainless Steel	35000	to	65,000 psi
6061 Aluminum	9000	to	14,000 psi

The method used on this work, pinpoints the endurance limit within 1%-2% variation as can be seen from the illustrated figures.

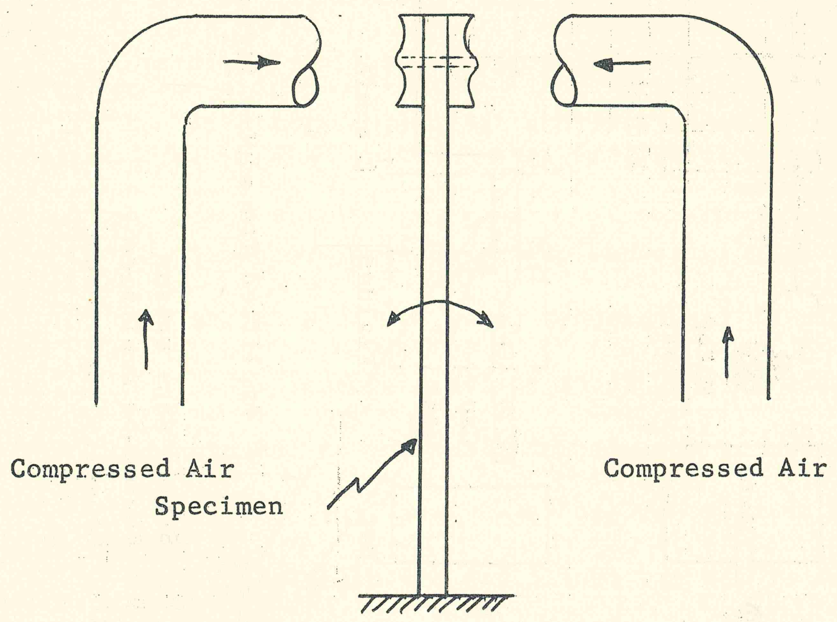


Fig. 1a Pneumatic Fatigue Set-up

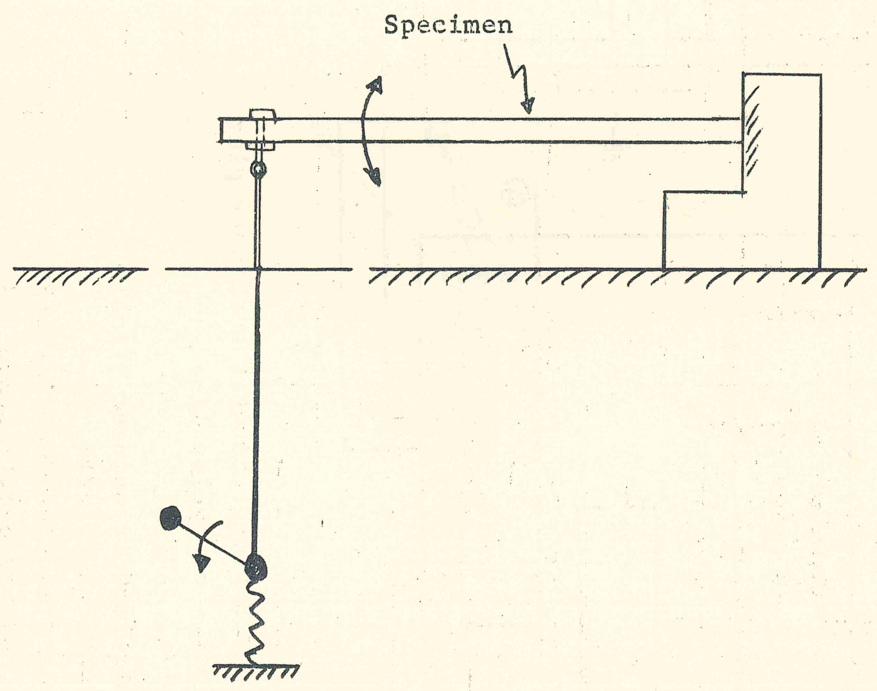
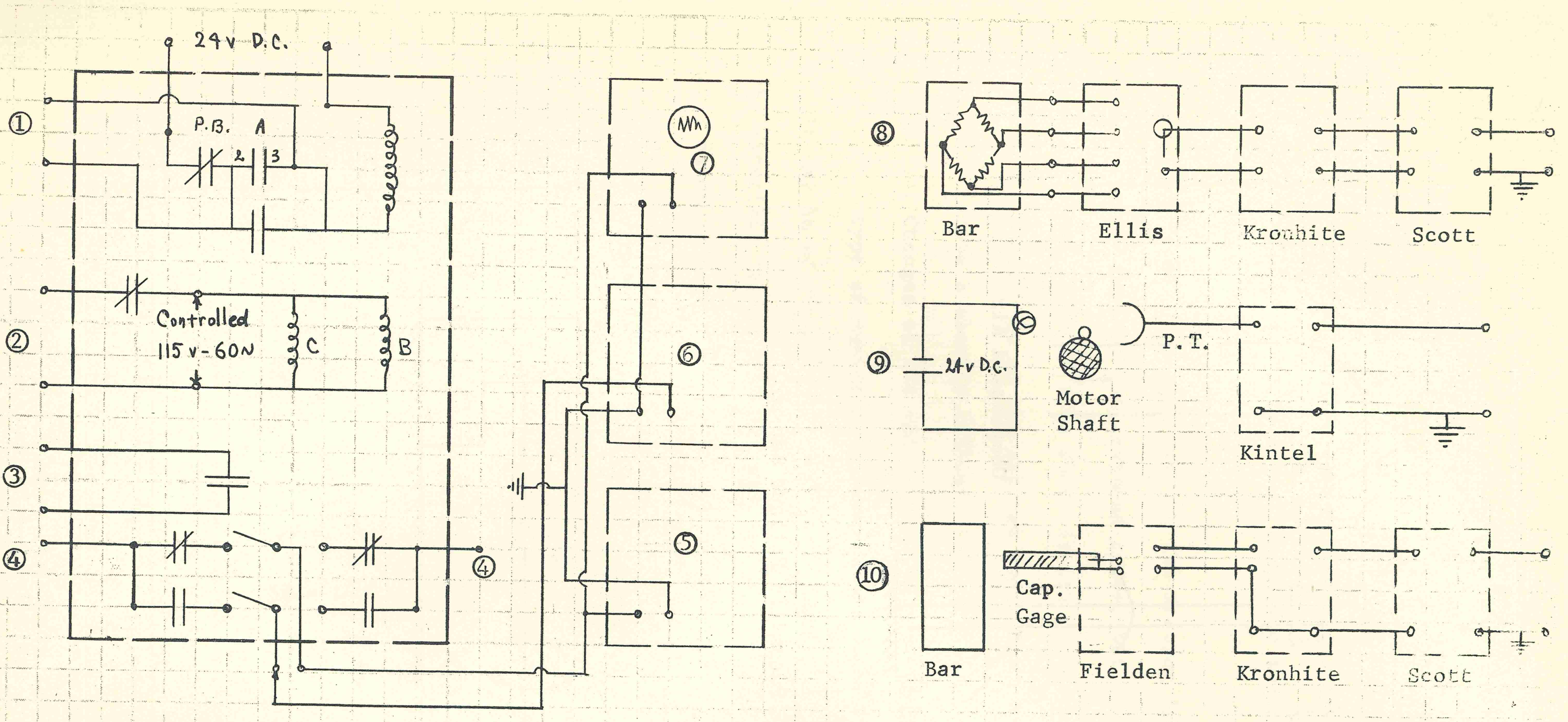


Fig. 1b Conventional (Sontag) Machine Set-up


24 v D.C.
①
P.B. A
2
3
②
Controlled 115 v - 60 ~
C
B
③
④
④
⑦
⑥
⑤
⑧
Bar
Ellis
Kronhite
Scott
⑨
24 v D.C.
Motor Shaft
P. T.
Kintel
⑩
Bar
Cap. Gage
Fielden
Kronhite
Scott

Amplified Transducer Signals

1 B and H preset counter accessory plug
2 115 v - 60 cycles line
3 Series contact
4 Amplified transducer signal
5 Counter H.P. 521A
6 Preset counter Berkeley 5426
7 Cathod ray oscilloscope

8 Strain gage sensor
9 Phototube amplifier
10 Capacity gage sensor

Fig. 2 Instrumentation-Counter Circuitry

Fig. 3 "Damping" vs. Stress

Material - Stainless Steel 347
Cycles - 10,000 freq. 55 cps
Bar # B-7

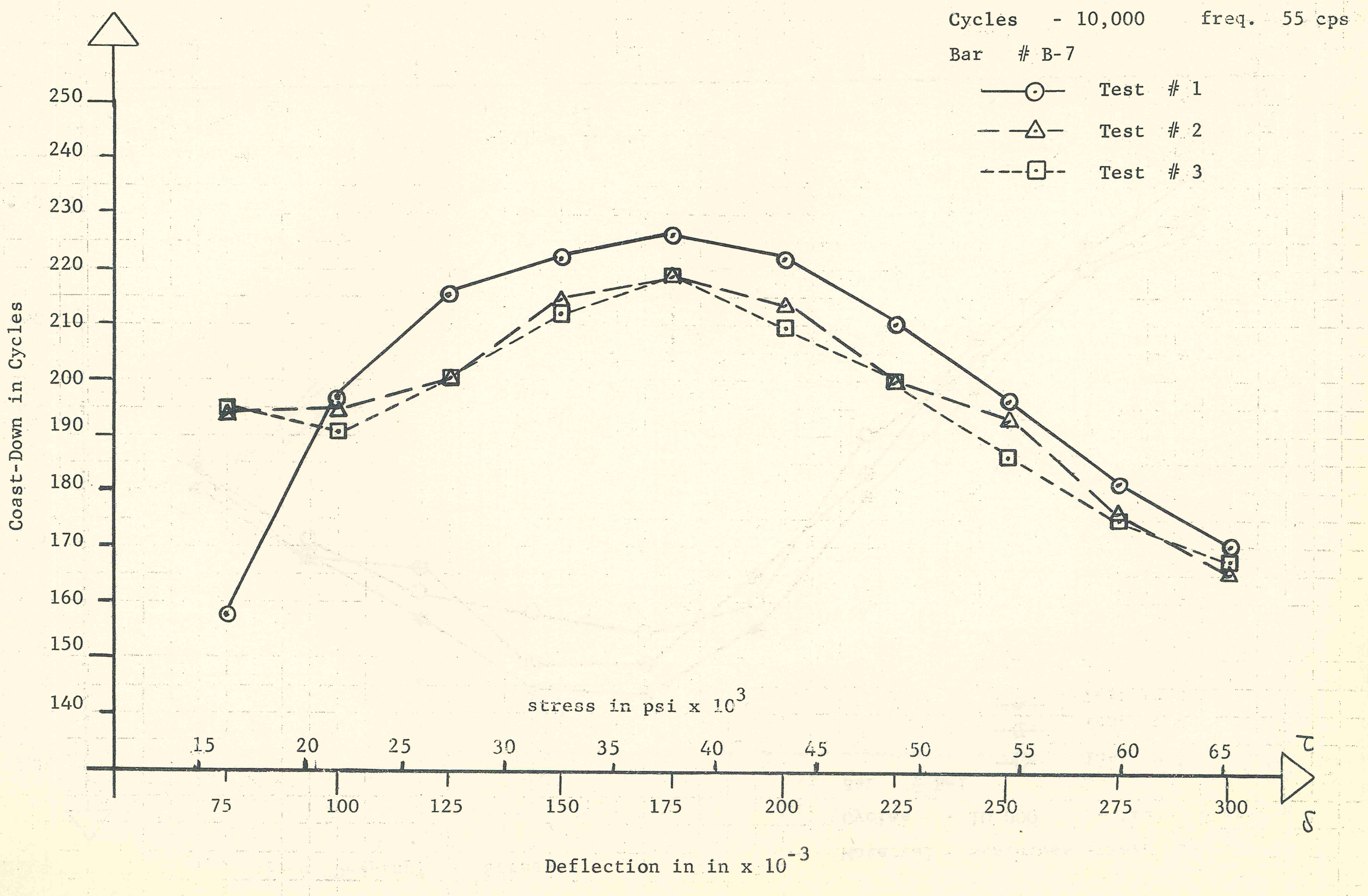


Fig. 4 "Damping" vs. Stress

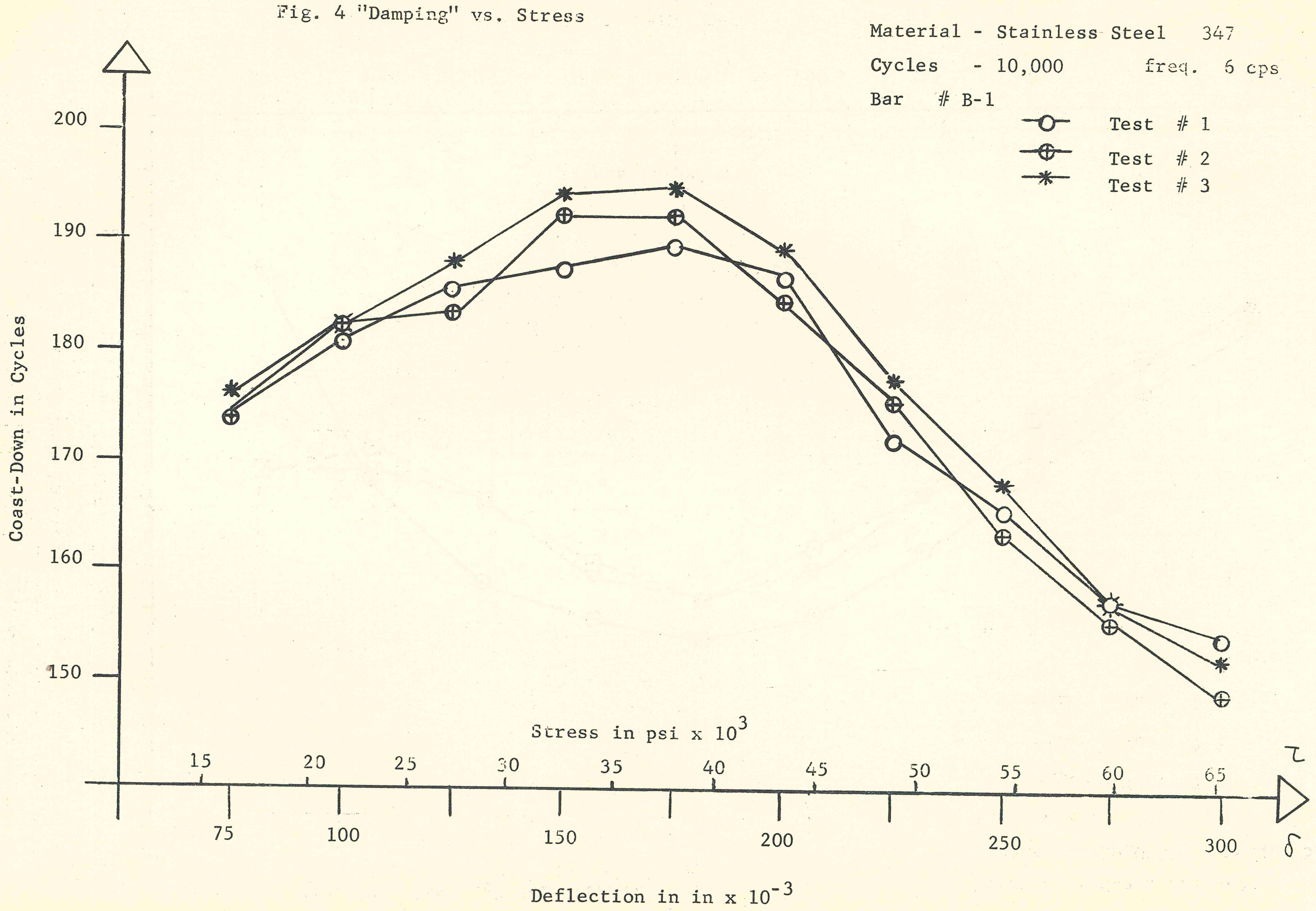


Fig. 5 "Damping" vs. Stress

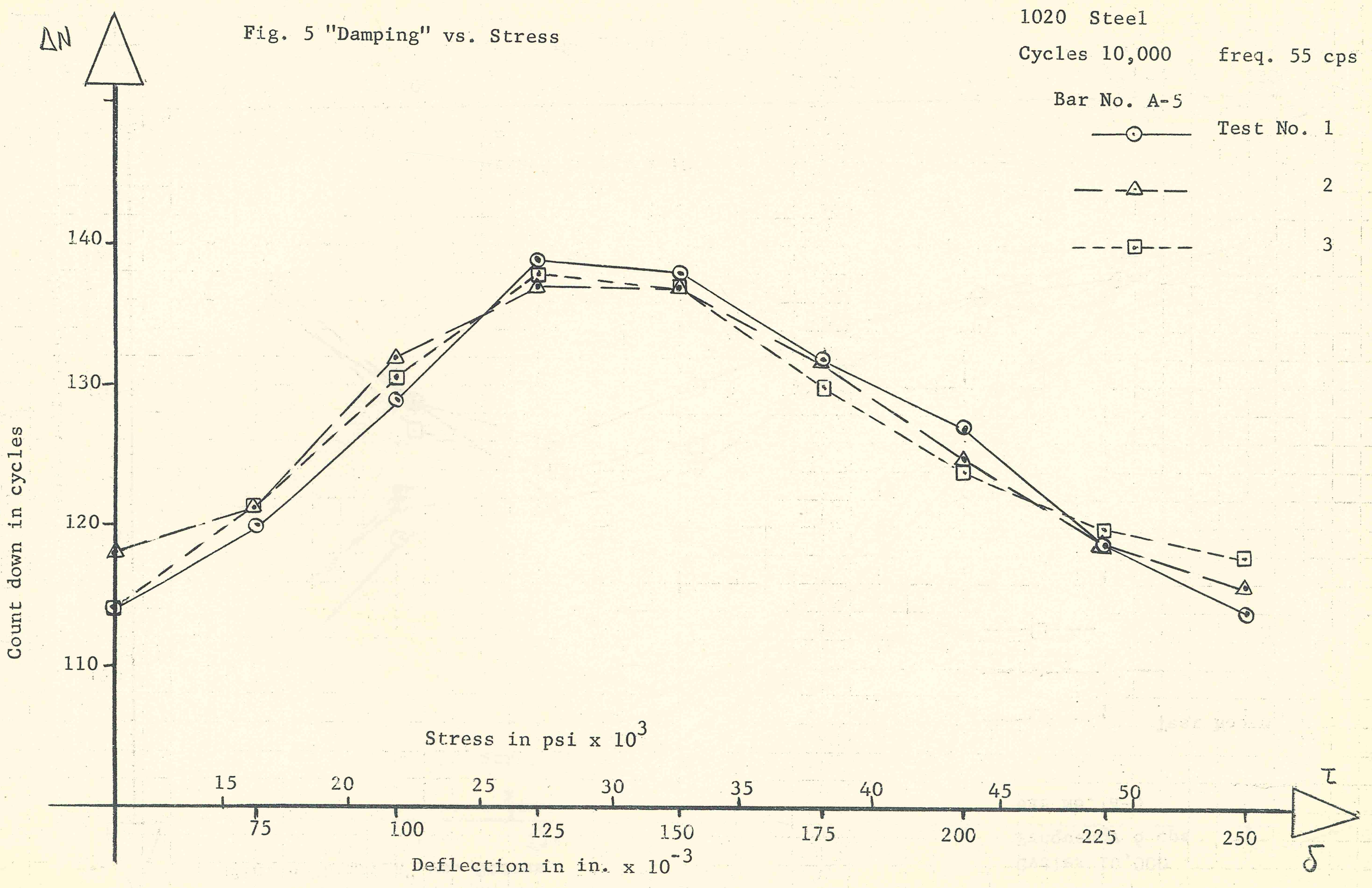


Fig. 6 "Damping" vs. Stress

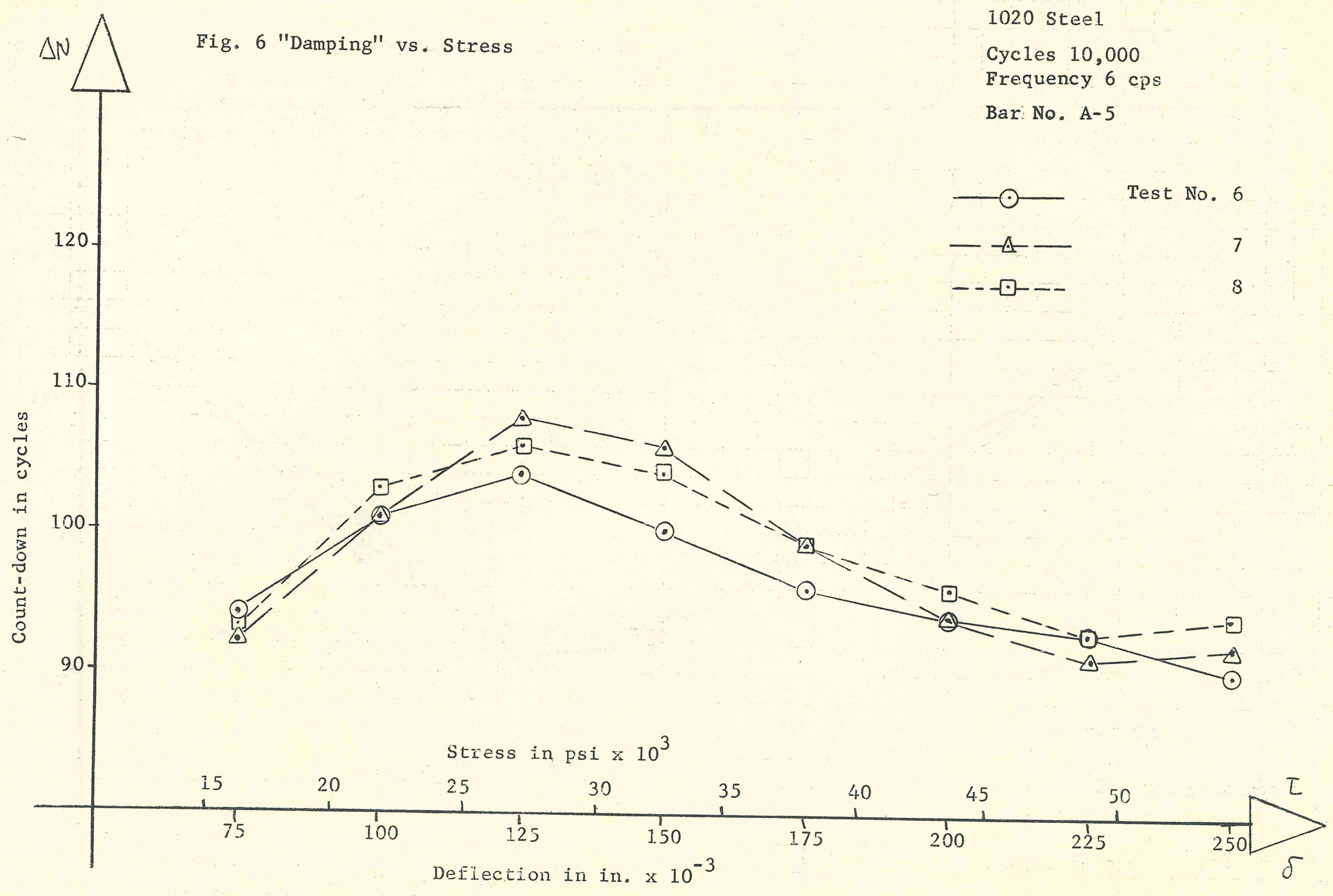


Fig. 7 "Damping" vs. Stress

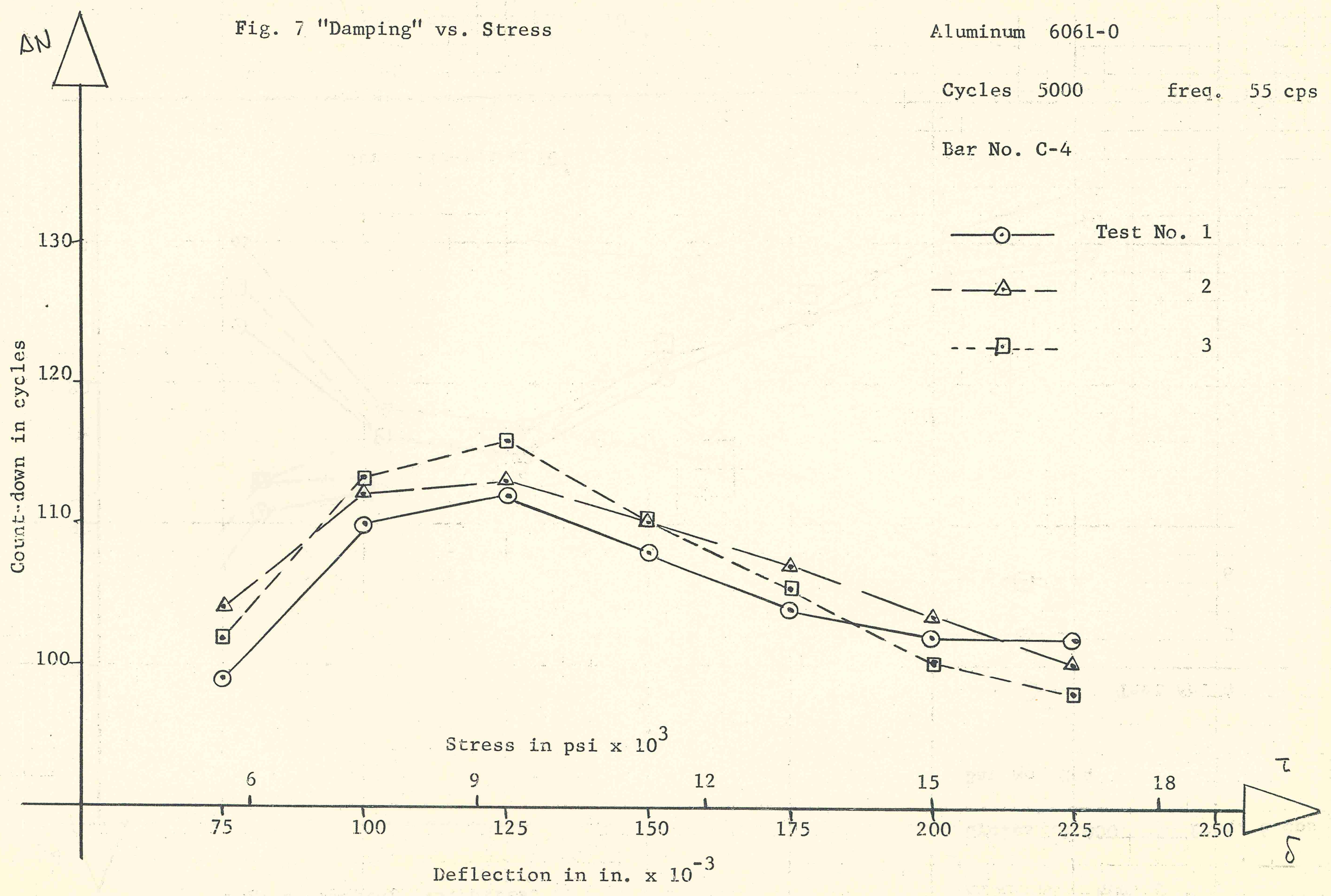


Fig. 8 "Damping" vs. Stress

Aluminum 6061-0

Cycles 5,000 freq. 6 cps

Bar No. C-4

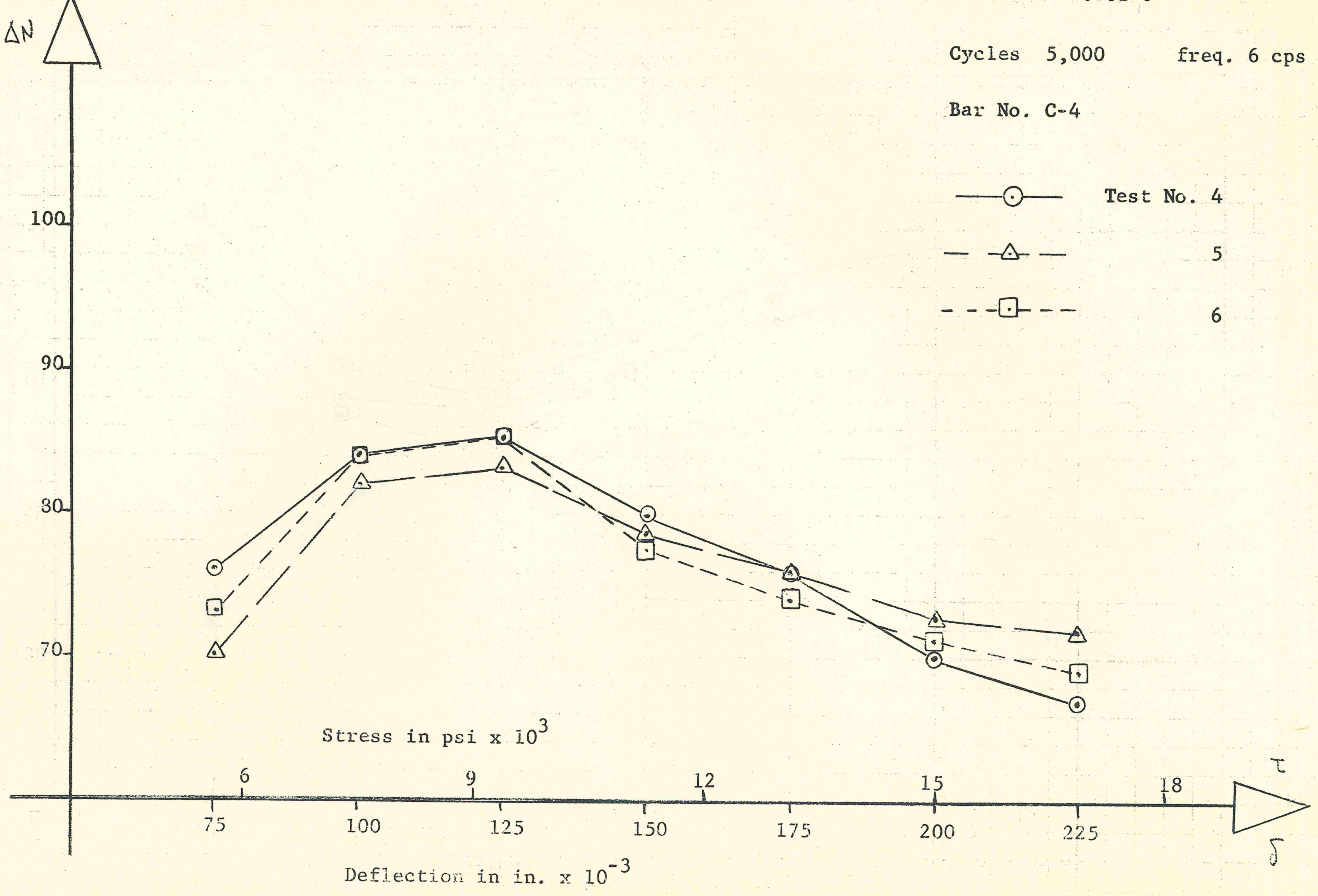


Fig. 9 "Damping" vs. Stress

Material - 1020 Steel

Cycles - 1000

Bar # A-4

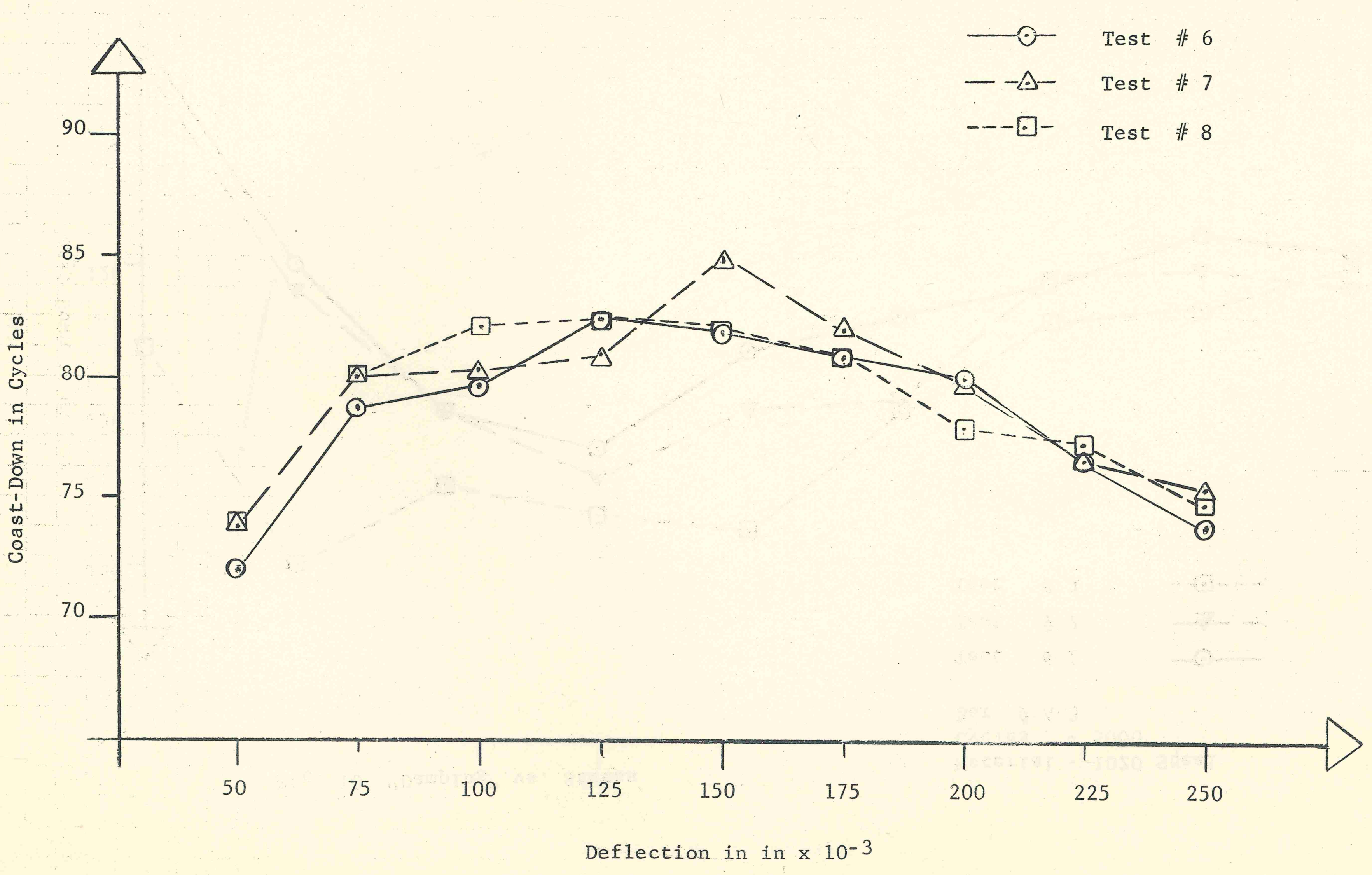


Fig. 10 "Damping" vs. Stress

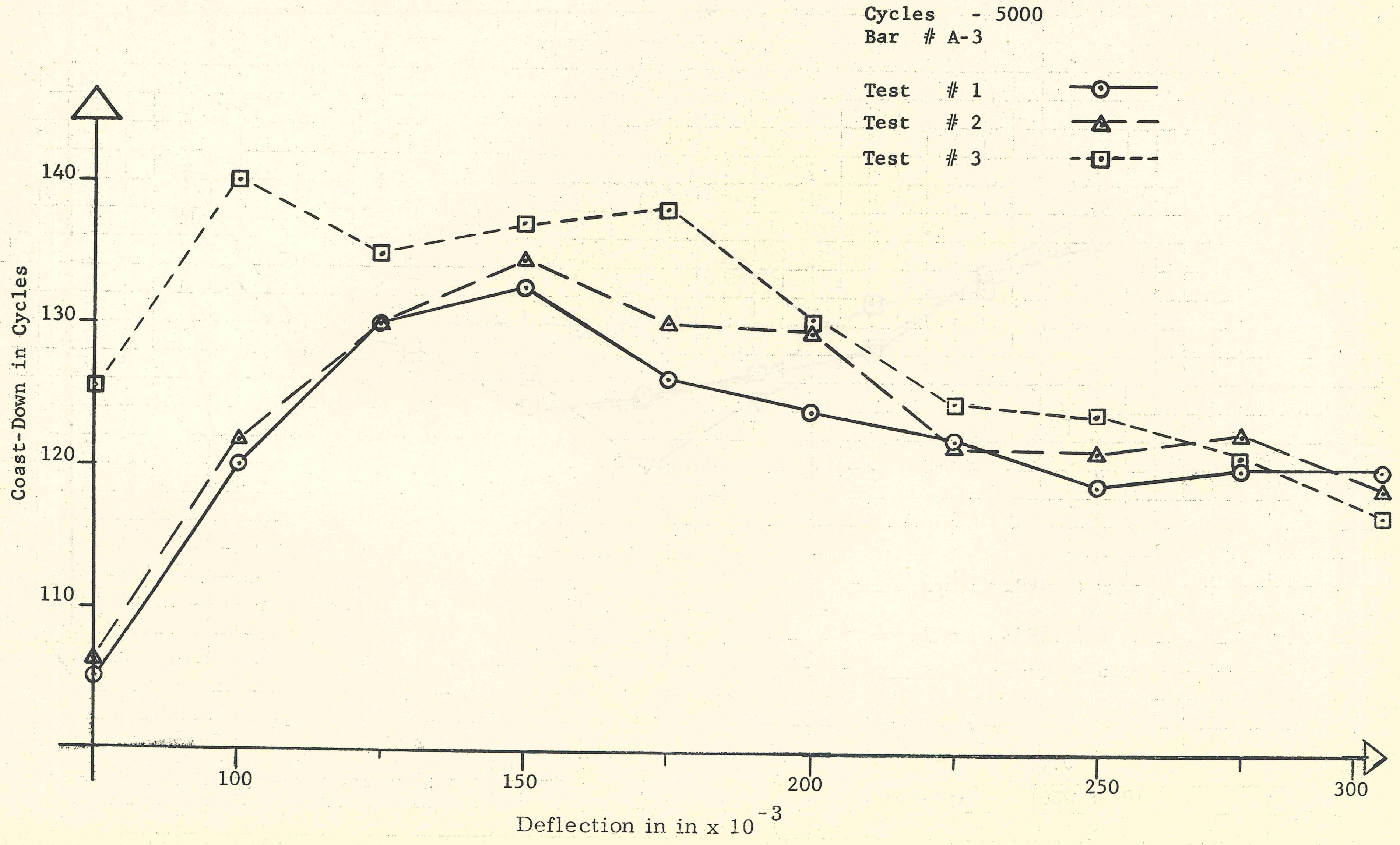
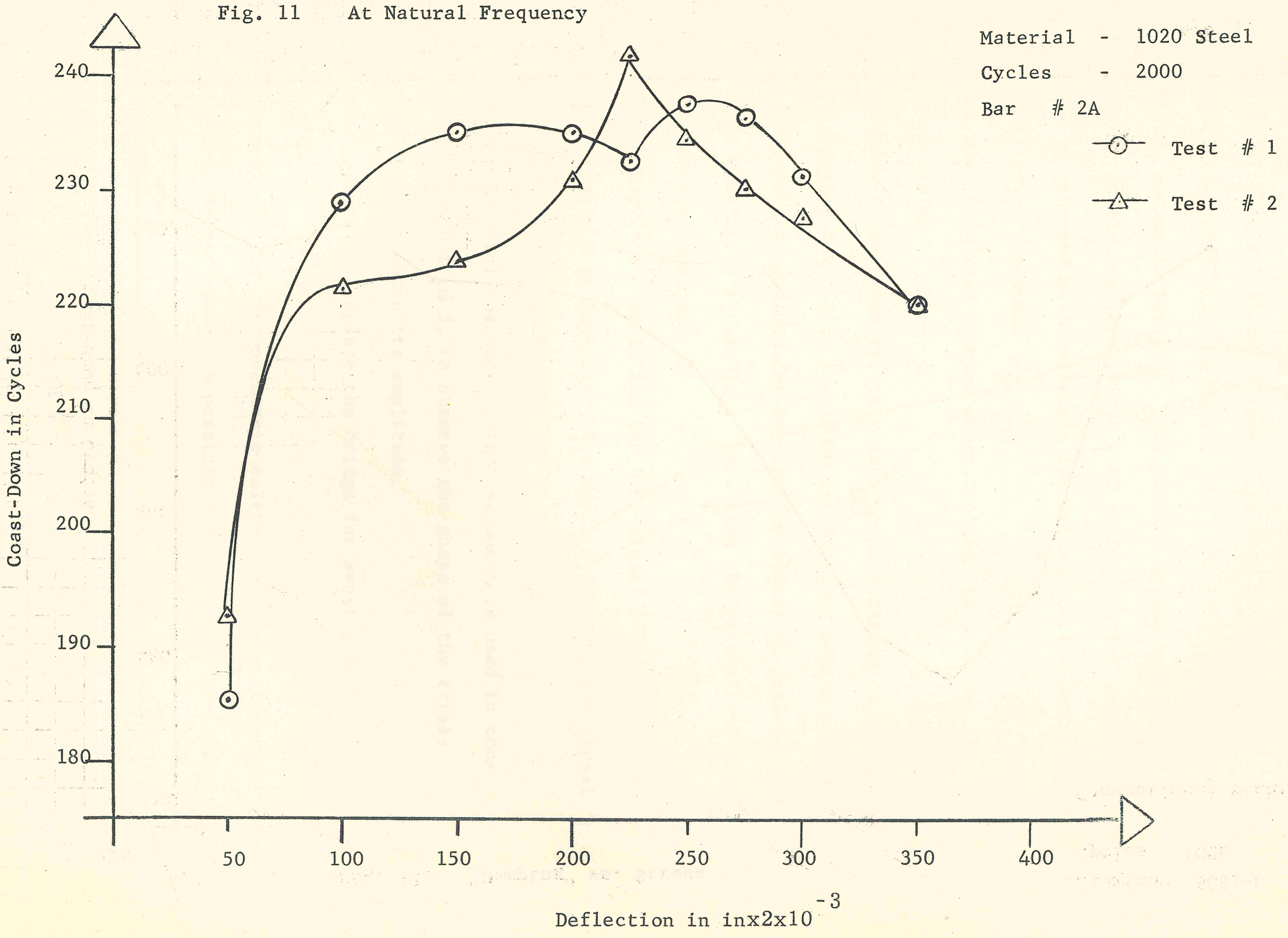


Fig. 11 At Natural Frequency



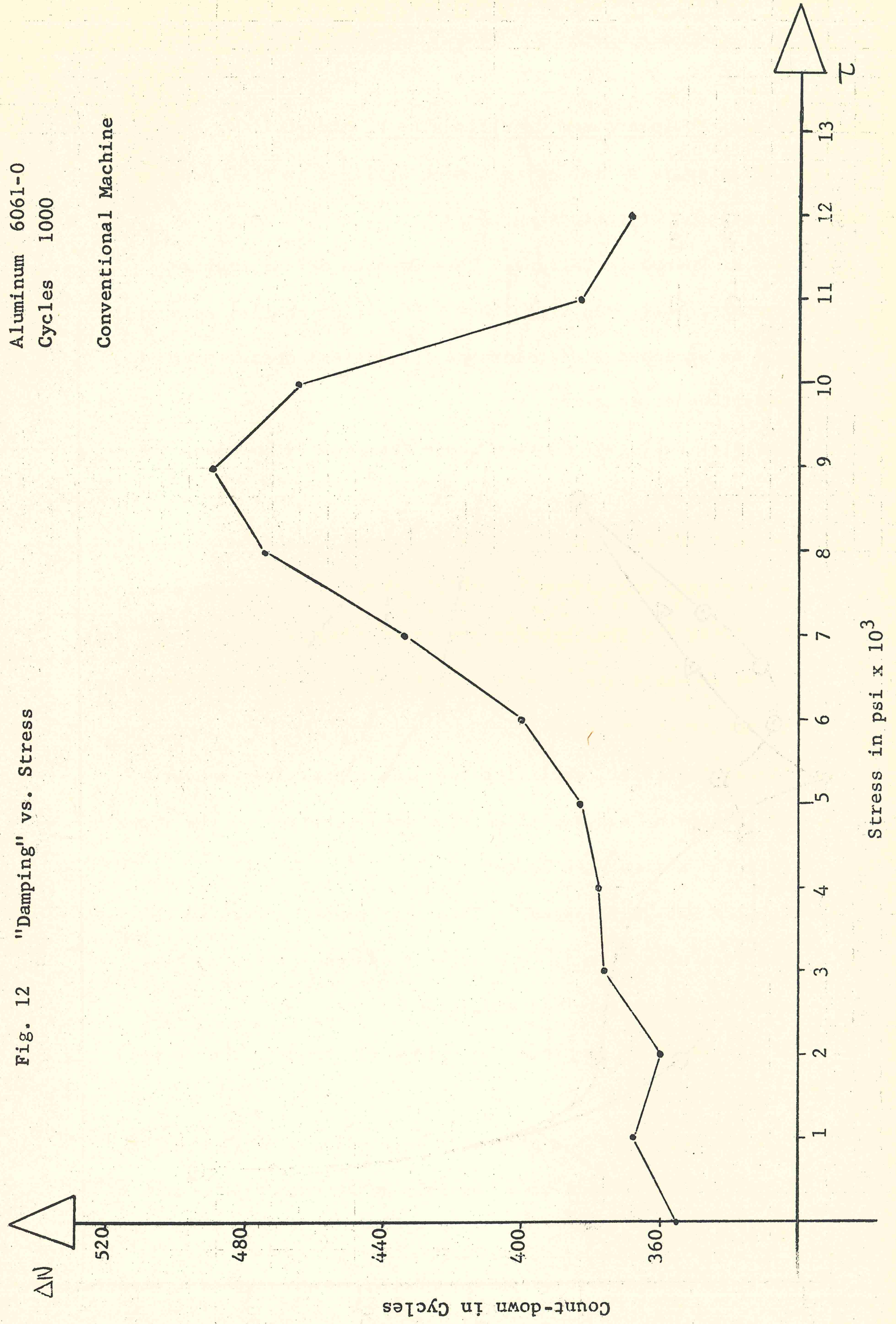


Fig. 12 "Damping" vs. Stress

Appendix: Test Equipment and Conditions by F. Madden

The following is a list of equipment utilized in this program along with a short description of their function:

1. A G.E. Pneumatic Fatigue. This machine drives specimen pneumatically, contains 110 v - 60 cycles control solenoid, and is equipped with telescope for optical measurement of amplitude of specimen.
2. Berkeley Universal Counter whose function is to count the decay cycles.
3. Berkeley Preset Counter, this instrument contains an adjustable preset count from 1 - 10000 cycles, thus making possible to stress the specimen for any desired number of cycles. Both these counters are capable of measuring the natural and driven frequency of specimen.
4. Kintel Amplifier, amplifies the D.C. signal from sensor.
5. Ellis Strain Gage Amplifier, for amplification of the signal from the strain gage sensor.
6. Cathode Ray Oscilloscope. This instrument is used in conjunction with item 5, to observe the shape of the stress cycling and measure its amplitude.
7. Strain gages to complete the bridge for sensing the stress field.
8. Control relay for the pneumatic solenoid and decay counter.
9. Capacity Probe, used as a possible substitute to the strain gage sensors.

It was found that while the strain gages have the apparent disadvantage of requiring time to be mounted on the specimen they are preferable, at this stage of the investigation, to the easily used capacity probes which are gap sensitive and non-linear in response.

It should be noted that as the investigation of fatigue phenomena continues and different materials and conditions are introduced, new instrumentation problems will inevitably be encountered. Therefore, the set-up used in this study should not be considered as final or most efficient one.